Influence of Oil on Heat Transfer Characteristics of R410A Flow Boiling in Conventional and Small Size Microfin Tubes

Haitao HU [1], Hao PENG [2], Guoliang DING [1,*], Yongxin ZHENG [3], Yifeng GAO [3], Ji SONG [3]

[1] Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai, China

[2] Key Lab of HVAC, Beijing University of Civil Engineering and Architecture, Beijing, China

[3] International Copper Association Shanghai Office, Shanghai, China

Outline

- Background
- Experiment Setup
- Experimental Result and Discussion
- HTC Correlation Development
- Conclusions

Background

Advantage of small diameter tubes:

- **Cost and volume can be reduced;**
- **Refrigerant charge can be reduced**

Tube diameter:
9.52 mm
7.0 mm

Previous

→

Tube diameter:
5.0 mm

Now

→

Smaller diameter
4.0 mm or smaller

Future

For 7 mm → 5 mm:
Advantage— about 50% copper saving
Disadvantage—Pressure loss increasing, COP decreasing

↓

Optimization design is necessary! → **Flow boiling in small diameter tubes**

Literature review:

Table 1: Existing researches on the correlation for Ref/oil in mircofin tubes

Literatures	Fluid	Tube diameter
Schlager *et al.* (1998)	R22/150-SUS	9.52 mm O.D.
	R22/300-SUS	9.52 mm O.D.
Eckels *et al.* (1994, 1998)	R134a/169-SUS	9.52 mm O.D.
	R134a/369-SUS	9.52 mm O.D.
	R134a/150-SUS	9.52 mm O.D.
Nidegger *et al.* (1997)	R134a/oil	11.9 mm I.D.
Usmani and Ravigururajan (1999)	R12, R22, R113, R134a/oil	8.51-8.92 mm I.D.
Targanski and Cieslinski (2007)	R407C/oil	10.0 mm O.D.
Hu *et al.* (2008)	R410A/POE oil	7.0 mm O.D.

$D \geq 7.0$ mm

Literature review:

1) Oil-free R410A in tubes (>6.0 mm)

2) R410A-oil mixture in 7.0 mm microfin tube.

3) R22, R407C, R134a, CO_2 and oil in microfin tubes (>6.0mm)

- ✓ **N**o research on R410A-oil in small diameter microfin tubes
- ✓ Flow and heat transfer performance are different for the tubes with different diameters.

Research content:

R410A-oil mixture flow boiling in conventional (≥7.0 mm) and small size (4-5 mm O.D.) microfin tubes

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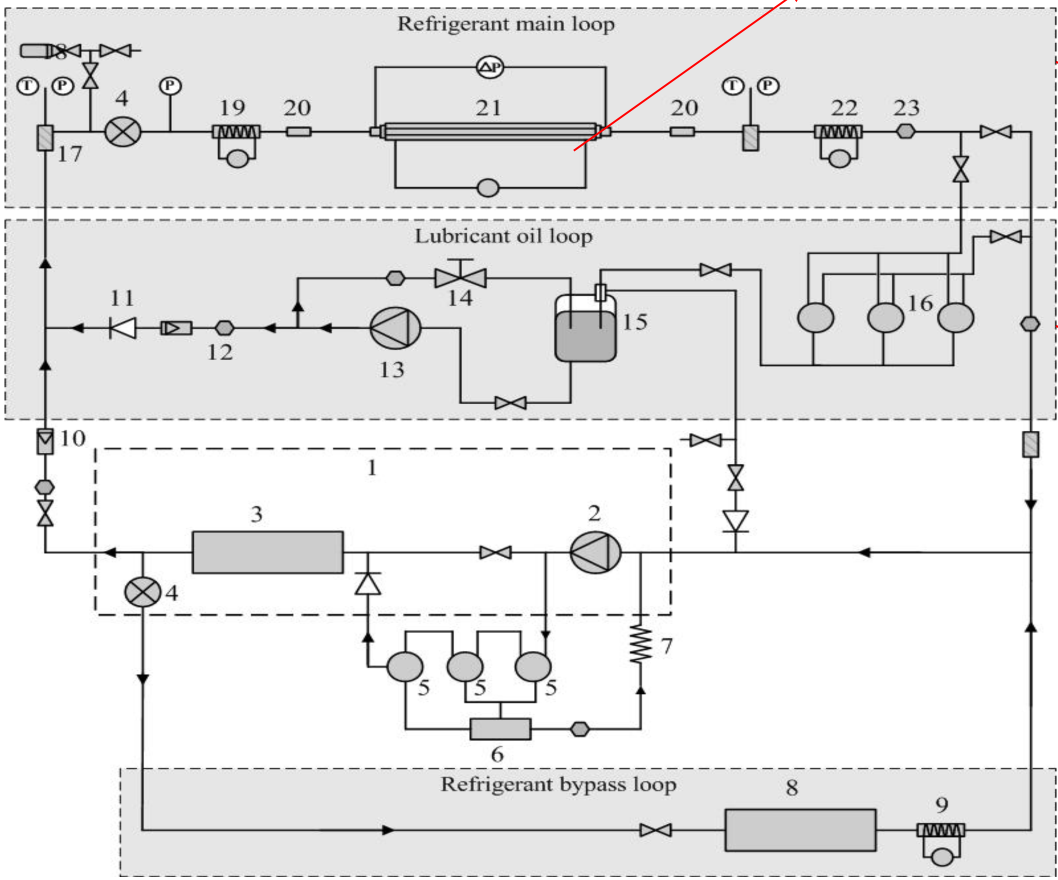
Experiment Setup

Test section



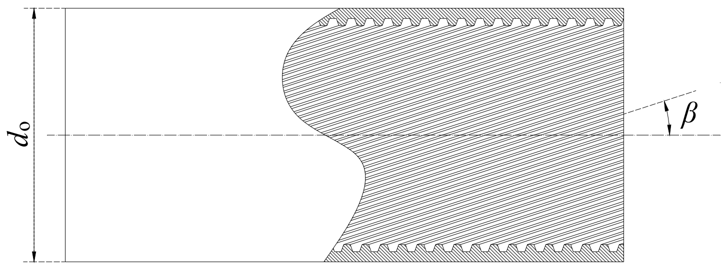
Refrigerant main loop:
adjusting test condition

Oil loop:
(on-line oil injection; adjusting oil concentration of test section)

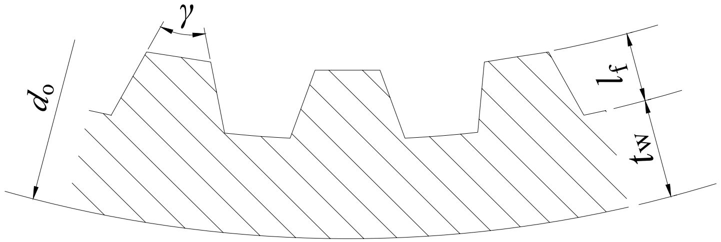
Refrigerant bypass loop:
adjusting refrigerant mass flow rate

Test tubes

Test tube: 4.0-5.0 mm microfin tubes tubes



(a) Cutaway view of the tested tube



(b) Cross section of fin

Figure 1 The schematic of internally spiral grooved tubes

Table 2: Details of enhanced tubes

parameter	Tube In existing literature	tube#1	tube#2	tube#3
d_o / mm	7.00	5.00	5.00	4.00
t_w / mm	0.25	0.20	0.20	0.22
l_f / mm	0.18	0.14	0.155	0.12
n_f	50	40	48	40
β / °	18	18	18	12
γ / °	40	40	20	40

New data

All data are used for developing correlation

Table 3: Test conditions of the test tubes

Test tube	Tube diameter (mm)	Mass flux (kg/m²·s)	Heat flux (kW/m²)	Inlet quality	Outlet pressure (kPa)	Oil concentration (wt. %)	Data points
tube#1	5.0 mm	200±10	7.46	0.1~0.8	934±5	0,1,2,3,4,5	292
		300±10	11.2	0.1~0.8	934±5	0,1,2,3,4,5	
		400±10	14.9	0.1~0.8	934±5	0,1,2,3,4,5	
tube#2	5.0 mm	200±10	7.46	0.2~0.8	934±5	0, 1, 3, 5	
		300±10	11.2	0.2~0.8	934±5	0, 1, 3, 5	
		400±10	14.9	0.2~0.8	934±5	0, 1, 3, 5	
tube#3	4.0 mm	300±10	12.63	0.1~0.8	934±5	0, 1, 3, 5	
		400±10	16.84	0.1~0.8	934±5	0, 1, 3, 5	

Uncertainties of instruments and heat transfer coefficient

Parameters	Source of uncertainty	Instrument	Range	Uncertainty
Refrigerant mass flow rate	Instrumentation calibration	Coriolis-effect flowmeter	0~200 kg/h	±0.12% FS
Oil mass flow rate	Instrumentation calibration	Coriolis-effect flowmeter	0~20 kg/h	±0.12% FS
Temperature	Instrumentation calibration	T-Type thermocouple	-20~100 °C	±0.1°C
Pressure	Instrumentation calibration	Absolute pressure transducer	0~2 MPa	±0.12% FS
Uncertainties of heat transfer coefficient				±10.4%

$$\begin{cases} \alpha_{\mathrm{tp,r}} = q/\left(T_{\mathrm{w}} - T_{\mathrm{bub,r}}\right) \\ \alpha_{\mathrm{tp,r,o}} = q/\left(T_{\mathrm{w}} - T_{\mathrm{bub,r,o}}\right) \end{cases}$$

$$\begin{cases} \omega_{\mathrm{no}} = m_{\mathrm{o}}/\left(m_{\mathrm{o}} + m_{\mathrm{r}}\right) \\ \omega_{\mathrm{local}} = \dfrac{m_{\mathrm{o}}}{m_{\mathrm{o}} + m_{\mathrm{r,L}}} = \dfrac{\omega_{\mathrm{no}}}{1 - x_{\mathrm{r,o}}} \end{cases}$$

0~5 wt.%

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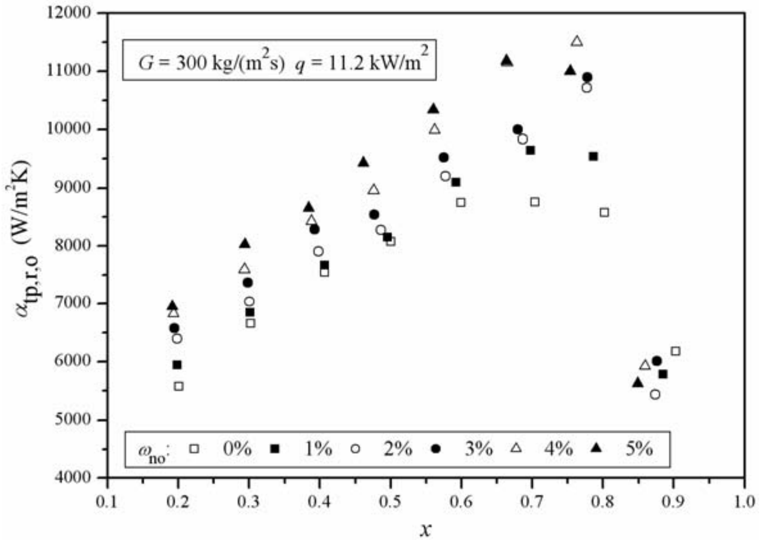
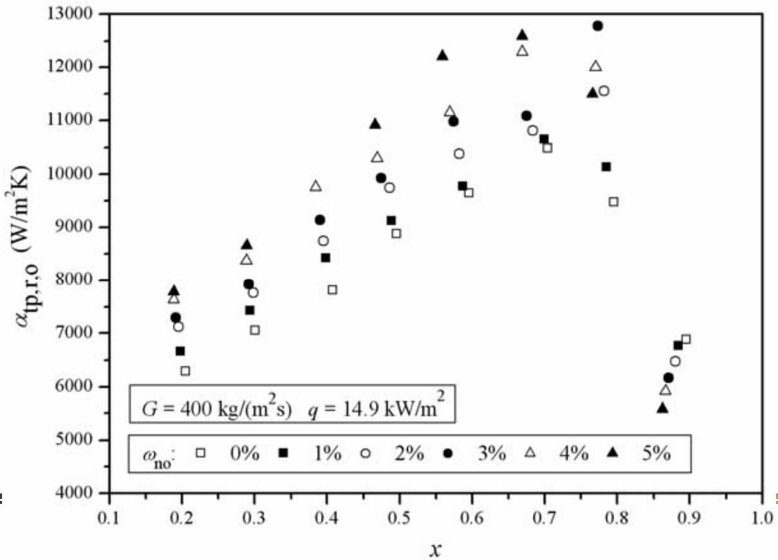
Result and Discussion

- Heat transfer coefficient in 5.0 mm microfin tube#1





For oil-free R410A

$x_{r,o}$=0.6-0.7

x ↑ ⇨ $\alpha_{tp,r,o}$

For R410A-oil mixture

1) $x_{r,o}$< 0.7:

ω_{no} ↑ ⇨ $\alpha_{tp,r,o}$ ↑

2) $x_{r,o}$> 0.8:

ω_{no} = 3% ~ 5%

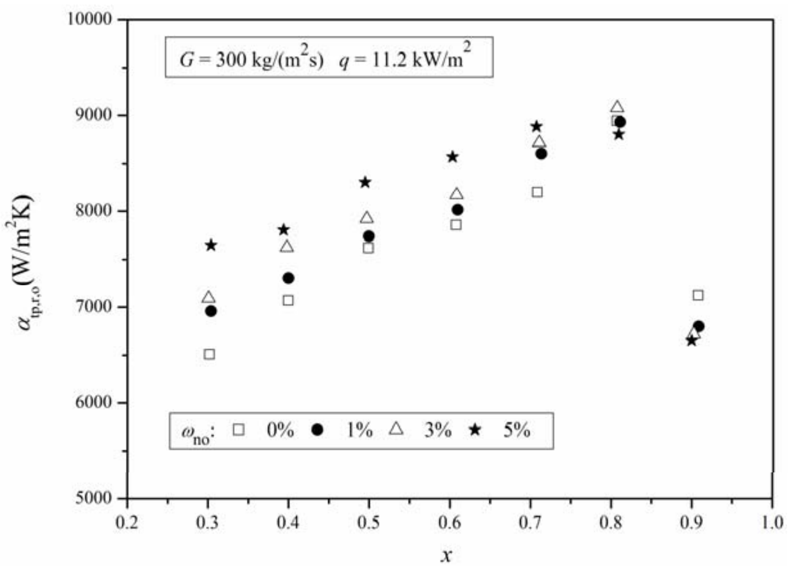
ω_{no} ↑ ⇨ $\alpha_{tp,r,o}$

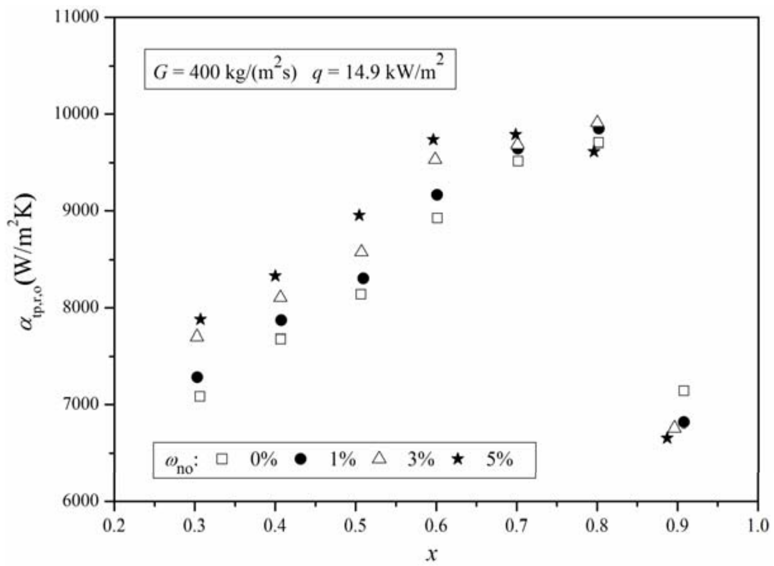
3) $x_{r,o}$> 0.85:

ω_{no} ↑ x ↑ ⇨ $\alpha_{tp,r,o}$ ↘

Result and Discussion

- Heat transfer coefficient in 5.0 mm O.D. microfin tube#2

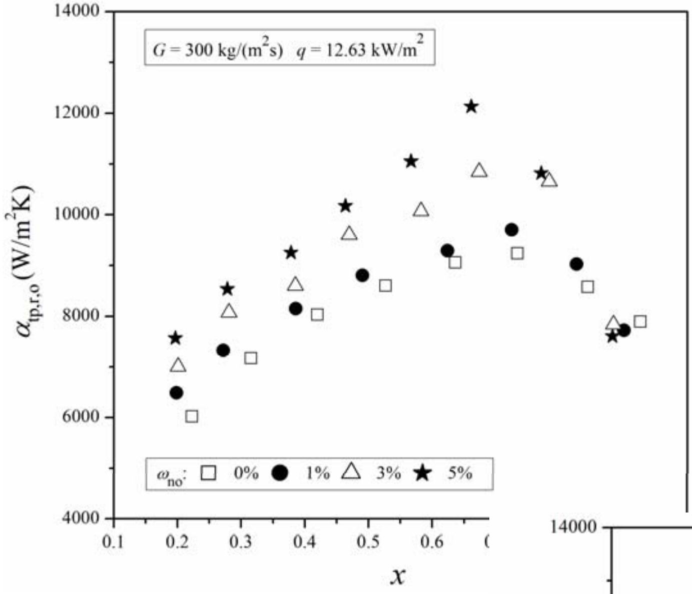


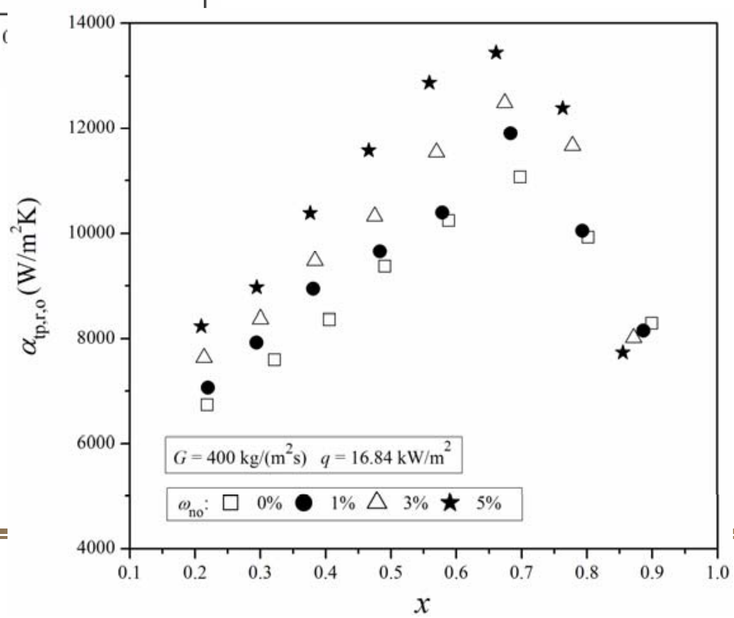


1) for oil-free R410A, HTC in tube#2 is always higher than that in tube#1;
2) for R410A-oil mixture, at $x_{r,o} < 0.5$, HTC in tube#2 is 5%~15% higher than that in tube#1;
3) at intermediate vapor qualities, HTC in tube#2 is 10% ~ 15% lower than that in tube#1;
4) while at $x_{r,o} > 0.8$, HTC in tube#2 is 10% ~ 25% higher than that in tube#1.

Result and Discussion

- Heat transfer coefficient in 4.0 mm microfin tube#3





For oil-free R410A

$x_{r,o}$=0.6-0.7

x ↑ ⇒ $\alpha_{tp,r,o}$ ↗↘

For R410A-oil mixture

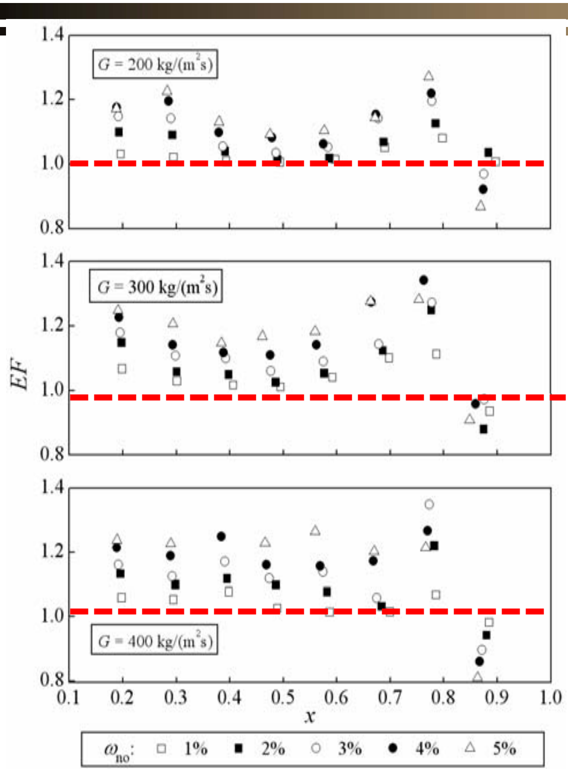
1) $x_{r,o}$< 0.7:

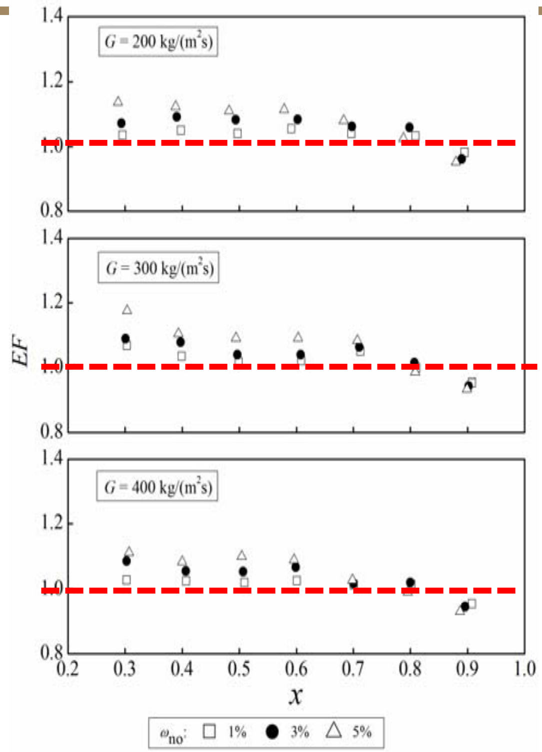
ω_{no} ↑ ⇒ $\alpha_{tp,r,o}$ ↑

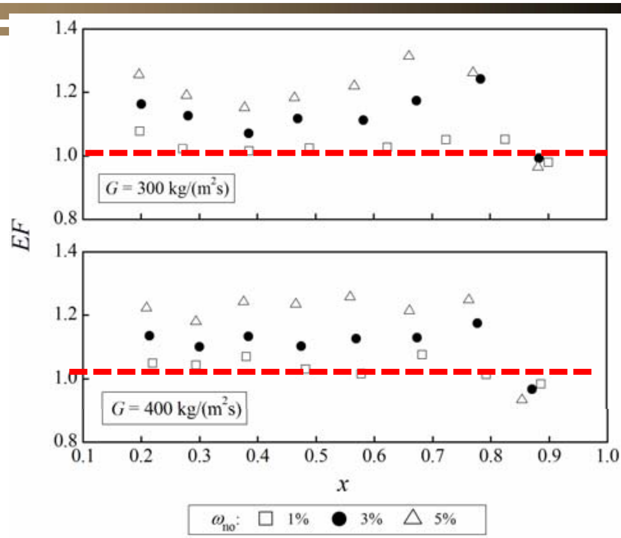
2) $x_{r,o}$> 0.8:

ω_{no} ↑ x ↑ ⇒ $\alpha_{tp,r,o}$ ↘

Result and Discussion







$$EF = \alpha_{\mathrm{tp,r,o}} / \alpha_{\mathrm{tp,r}}$$

Results:

- ✓ for 5.0 mm microfin tubes, *EF* are within 0.8~1.37 and 0.95~1.18 for tube#1 and tube#2, respectively, and *EF* of tube#2 is smaller than that of tube#1 at *x<0.8* while larger than that of tube#1 at x> 0.8;
- ✓ for 4 mm microfin tube, the range of the enhancement factor are within 0.93~1.26.

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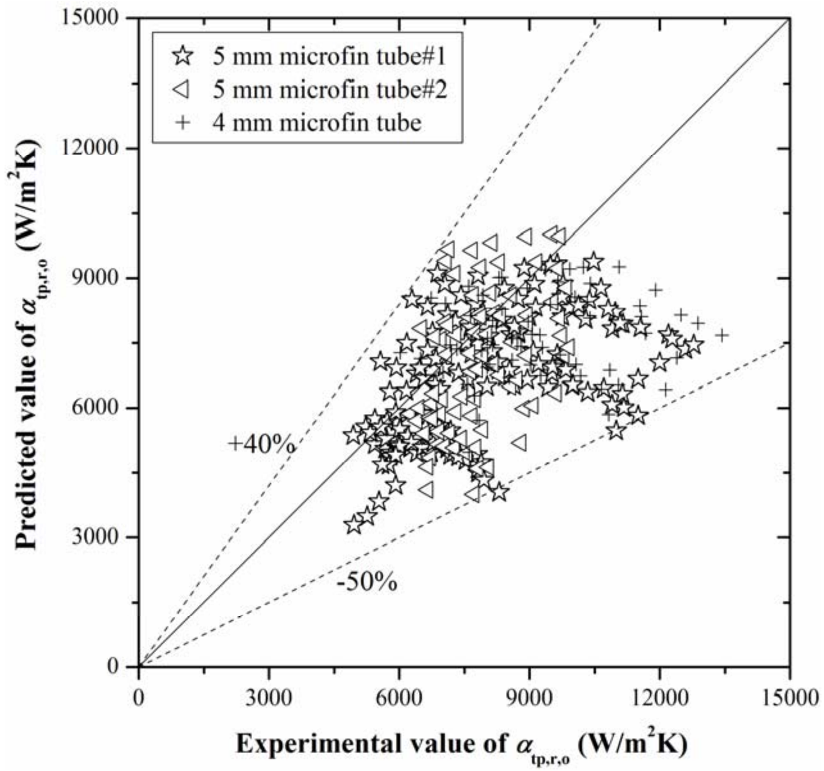
Correlation development

- Prediction ability of existing correlation for R410A/oil



$$\alpha_{r,o,tp} = E\alpha_{r,o,L} + S\alpha_{r,o,nb}$$

$$\alpha_{r,o,L} = 0.023 E_{RB} \frac{\lambda_{r,o,L}}{d_f} \mathrm{Re}_{r,o,L}^{0.8} \mathrm{Pr}_{r,o,L}^{0.4}$$

$$\alpha_{r,o,nb} = 55 P_{re}^{0.12} (-\log_{10} P_{re})^{-0.55} M^{-0.5} q_{im}^{0.67}$$

$$E = 1 + b_1 Bo^{1.16} + b_2 X_{tt}^{-0.86}$$

$$S = \frac{1}{1 + c_1 E^{c_2} \mathrm{Re}_{r,o,L}^{1.17}}$$

Should be refitted

Correlation development

- New correlation development

$$\alpha_{r,o,tp} = E\alpha_{r,o,L} + S\alpha_{r,o,nb}$$

$$\alpha_{r,o,L} = 0.023 E_{RB} \frac{\lambda_{r,o,L}}{d_f} \mathrm{Re}_{r,o,L}^{0.8} \mathrm{Pr}_{r,o,L}^{0.4}$$

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$$E = 1 + b_1 Bo^{1.16} + b_2 X_{tt}^{-0.86}$$

$$S = \frac{1}{1 + c_1 E^{c_2} \mathrm{Re}_{r,o,L}^{1.17}}$$

Should be refitted

$$\alpha_{r,o,nb} = \frac{q_{im}}{\Delta T_b}$$

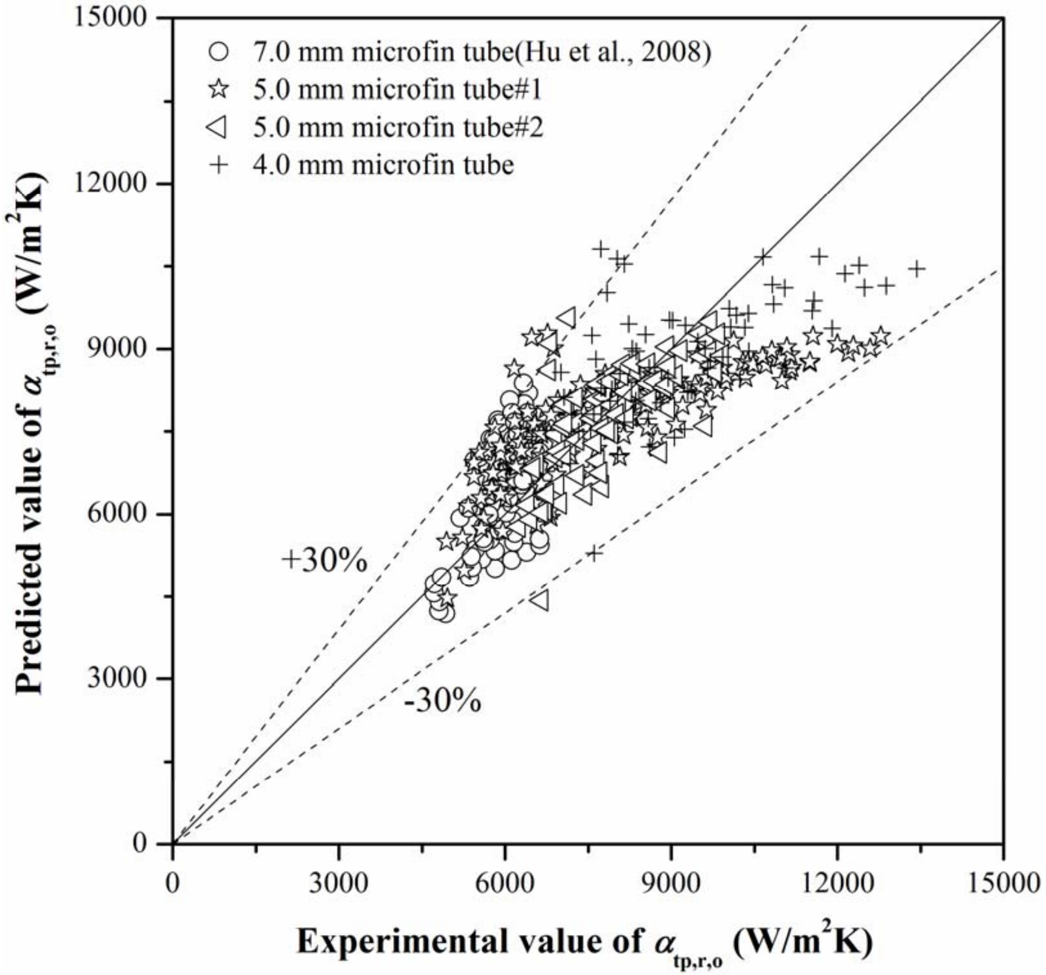
$$\Delta T_b = C_{sf} \frac{h_{fg}}{c_{p,r,o}} \left[\frac{q_{im}}{\mu_{r,o} h_{fg}} \sqrt{\frac{\sigma_{r,o}}{g(\rho_{r,o} - \rho_g)}} \right]^{0.33} \left(\frac{c_{p,r,o} \mu_{r,o}}{\lambda_{r,o}} \right)^{a_0}$$

$$C_{sf} = a_1 + a_2 \omega_{no} + a_3 SP_{wet} / SP_{bf}$$

Should be refitted

Correlation development

- New correlation development



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- The decrease of tube diameter may weaken the deterioration effect of oil on heat transfer at intermediate and high vapor qualities.

- For the fixed outside diameter microfin tubes with different microfin structures, larger fin height and contact area of liquid with tube wall may enhance the heat transfer for oil-free R410A, but result in smaller enhancement effect of oil at low vapor qualities and smaller deterioration effect of oil at intermediate and high vapor qualities for R410A-oil mixture due to more oil retained between the fins.

- A general correlation was developed for R410A-oil mixture inside the conventional size and small diameter microfin tubes, and the oil, tube diameter and micofin structures were reflected in the new correlation.

- The new correlation agrees with 94% of the experimental data within a deviation of ±30%.

Thank you !